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Opportunistic Energy Aware Scheduler For Wireless Networks

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Abstract—In the last decade, many research efforts have been done in order to increase the spectral efficiency of wireless communications. From now on, opportunistic resource allocations have emerged as the best way to reach this objective. They take into consideration the radio conditions in the allocation process. This allows to guarantee high system throughput and high Quality of Service (QoS). However, today, it is not sufficient anymore. Many climate problems have been underlined by the majority of world scientists and decreasing world greenhouse gas emission has become a necessity for the world's environment preservation. This requires to also reduce energy consumption in as much sectors as possible including wireless communication networks. This paper proposes to extend the opportunistic approach with the proposition of a new scheduling solution enables to significantly decrease the system energy consumption. Performance evaluations will show that the global energy consumption can be divided by 2 compared to existing schedulers without jeopardizing system efficiency.

Index Terms—Wireless Network, Green Networking, Energy Consumption, Opportunistic Scheduling, Multiuser diversity.

I. INTRODUCTION

Wireless networks have become a key of the society development. However, in contrast with wired communications, wireless transmissions are subject to many channel impairments such as path loss, shadowing and multipath fading [1]. These phenomena severely affect the transmission capabilities and in turn the energy consumption. In this context, the conventional access methods like Round Robin (RR) [2] and Random Access (RA) are obsolete. They are not adapted to the wireless environment and providing poor throughput. The past decades have witnessed intense research efforts on wireless digital communications. Among all the studied resource allocation approaches, one major has emerged and appeared in literature as the reference: opportunistic scheduling. Opportunistic schedulers preferably allocate the resources to the user(s) with the most favourable channel conditions at a given time. Taking benefit of time, multiuser and frequency diversity, they are able to maximize the system throughput. In this paper, two opportunistic schemes will be considered as references: Maximum Signal-to-Noise Ratio scheduler (MaxSNR) and Weighted Fair Opportunistic scheduler (WFO).

In MaxSNR, priority is given at each scheduling event to the users which have the greatest signal-to-noise ratio (SNR) [3], [4]. It dynamically adapts the modulation and coding. Taking profit of multiuser and frequency diversity, this allows to always make the most efficient use of the radio resource and coming closer to the Shannon limit.

MaxSNR strongly increases the system throughput. However, it manages any service differentiation and shows a severe lack of fairness in regards to users with different positions [5], different types of traffic, etc. Many works have been done in order to correct these problems with the proposition of a new opportunistic scheduler called WFO [6]. This scheduler extends the classical cross-layer approach taking into account both the physical layer specificities (transmission conditions) and the higher layer constraints (traffic patterns, QoS constraints, Bit Error Rate...). This results in an efficient scheme which guarantees the high service differentiation required by all multimedia networks. Providing a same spectral efficiency than MaxSNR but with more fairness, WFO bandwidth management is able to ensure great Quality of Experience (QoE) for a very large amount of wireless network users.

Despite that these two acknowledged schemes provide high spectral efficiency and, for the WFO, high QoS: this is not sufficient anymore. Today, the world's growing population and the growing global energy demands bring to a critical situation. They generate unsustainable development both environmental and economical. Consequently, reducing power consumption has become a necessity including in wireless networks and resources allocation process. This paper brings a new solution called "Opportunistic Energy Aware" scheduler (OEA). It proposes to radically change the classical opportunistic radio resource mapping. Built in an extended cross layer approach, its main principle is to minimize energy consumption exploiting active-sleep mode and channel condition together. Physical layer information is used in order to take advantage of time, frequency and multi-user diversities. Like previous opportunistic schemes, this will allow to reach high system capacity. Higher layer information are take into account in order to achieve the QoS requirements, in particular the Bit Error Rate (BER_{target}). At the MAC level, users buffer occupancy and device power consumption information are exploited in order to compress transmission time (i.e, active mode) acknowledged to be highly greedy in energy. At each scheduling event, OEA determines the best transmission opportunities and finds the most profitable resource mapping in terms of number of transmitted bits per Watt. Maximizing the sleeping-time duration while taking into account the channel conditions in the allocation process, OEA allows to make a better usage of radio resources than previous scheme, reaching high spectral efficiency and greatly reducing energy consumption.

The remainder of this paper is organized as follows. Section 2 provides a description of the system under study. Section

3 describes our proposition. Section 4 presents a detailed performance evaluation and Section 5 concludes the paper.

II. CONTEXT DESCRIPTION

In this paper, we consider a centralized and synchronized approach [7] and we focus on the allocation of radio resources among the set of users situated in the coverage zone of an access point. We focus our study in Multiple Input Multiple Output (MIMO) - OFDM technology which is acknowledged for outperforming other strategies in terms of spectral efficiency [8]. This allows to make a more efficient use of the scarce bandwidth since it offers the possibilities to take a maximal benefit of the frequency diversity in the opportunistic scheduling. The total available bandwidth is divided in sub-frequency bands, i.e. subcarriers. The radio resource is further divided in the time domain in frames. Each frame is itself divided in Time Slots (TS) of constant duration. The TS duration is an integer multiple of the OFDM symbol duration. The number of subcarriers is chosen so that the width of each sub-frequency band is less than the coherence bandwidth of the channel. Moreover, the frame duration is fixed to a value much smaller than the coherence time of the channel. With these assumptions, the transmission on each subcarrier is subject to flat fading with a channel state that can be considered static during each frame. However, the transmissions performed on different subcarriers by different users are assumed to have independent channel state values [9]. In addition, the elementary resource unit (RU) is defined as any (subcarrier, TS) pair. Each of this RU may be allocated to any user with a specific modulation order. On each RU, the modulation scheme is QAM with a modulation order adapted to the channel state between the access point and the user to which it is allocated. This provides the flexible resource allocation framework required for opportunistic scheduling.

III. OPPORTUNISTIC ENERGY AWARE SCHEDULER

The OEA scheduler, located in the access node, grants RUs to each user as a function of: its QoS profile (BER target...), its different energy consumption mode (in active mode and sleep mode), its traffic backlog, its channel state... The QoS profile is signaled in the connection establishment phase. Additionally, knowledge of the channel state is supposed to be available at the receiver [10]. It is estimated by the access node based on the SNR of the signal sent by each user during the signaling phase. Assuming that the channel state is stable on a scale of 50 ms [11], and using a frame duration of 2 ms, the users shall transmit their control information alternatively on each subcarrier so that the access node may refresh the channel state information once every 25 frames.

The OEA scheduling algorithm relies on weights that set the dynamic priorities for allocating the radio resources. These weights are built in order to satisfy two major objectives: system throughput maximization and energy consumption minimization as explained below.

A. System Throughput Maximization

In wireless communication systems, the resources are limited. The frequency of commercial cellular systems are mostly obtained through the purchase which is always very expensive and scarce. Moreover, the infrastructure and equipment of wireless communication system are also very expensive. Therefore, a major problem of system design and optimization is to take full advantage of limited frequency and hardware resources in wireless communication systems and to ensure Quality of Service under the premise of providing the highest possible capacity. To achieve this goal, the resource management is the very important part.

The OEA optimizes the system throughput in a MAC/PHY opportunistic approach. Data integrity requirements of users are enforced considering each user independently adapting the modulation and the transmit power to the user specific channel state. At each scheduling epoch, the scheduler computes the maximum number of bits $m_{k,n}$ that can be transmitted in a TS of subcarrier n if assigned to user k , for all k and all n . This number of bits is limited by two main factors: the data integrity requirement and the supported modulation orders.

The bit error probability is upper bounded by the symbol error probability [3] and the TS duration is assumed equal to the duration T_s of an OFDM symbol. The required received power $P_r(q, k)$ for transmitting q bits in a RU while keeping below the data integrity requirement $BER_{target,k}$ of user k is a function of the modulation type, its order and the single-sided power spectral density of noise N_0 . For QAM and a modulation order M on a flat fading channel [12]:

$$P_r(q, k) = \frac{2N_0}{3T_s} \left[\operatorname{erfc}^{-1} \left(\frac{BER_{target,k}}{2} \right) \right]^2 (M - 1), \quad (1)$$

where $M = 2^q$ and erfc is the complementary error function. $P_r(q, k)$ may also be determined in practice based on BER history and updated according to information collected on experienced BER.

The transmit power $P_{k,n}$ of user k on subcarrier n is upper bounded to a value P_{max} which complies with the transmit Power Spectral Density regulation:

$$P_{k,n} \leq P_{max}. \quad (2)$$

Given the channel gain $a_{k,n}$ experienced by user k on subcarrier n (including path loss and Rayleigh fading):

$$P_r(q, k) \leq a_{k,n} P_{max}. \quad (3)$$

Hence, the maximum number of bits $q_{k,n}$ of user k which can be transmitted on a TS of subcarrier n while keeping below its BER target is:

$$q_{k,n} \leq \left\lfloor \log_2 \left(1 + \frac{3P_{max} \times T_s \times a_{k,n}}{2N_0 \left[\operatorname{erfc}^{-1} \left(\frac{BER_{target,k}}{2} \right) \right]^2} \right) \right\rfloor. \quad (4)$$

We further assume that the supported QAM modulation orders are limited such as q belongs to the set $S = \{0, 2, 4, \dots, q_{max}\}$. Hence, the maximum number of bits $m_{k,n}$

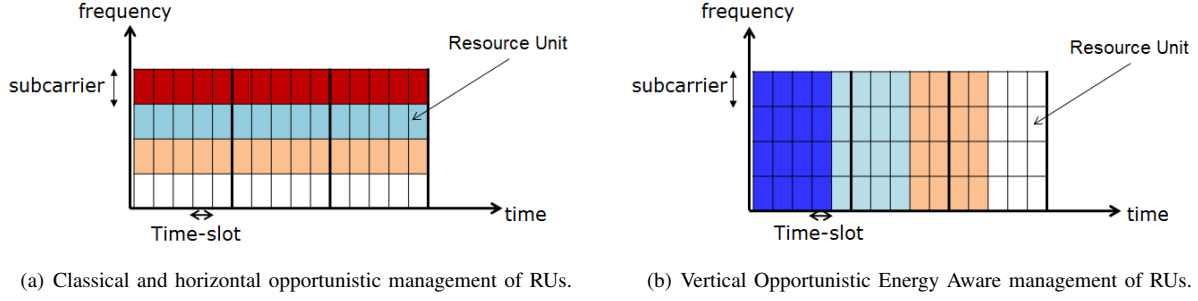


Fig. 1. Conceptual scheduling strategies.

that will be transmitted on a TS of subcarrier n if this RU is allocated to the service flow k is:

$$m_{k,n} = \max \{q \in S, q \leq q_{k,n}\}. \quad (5)$$

MaxSNR based schemes allocate the RU to the flows which have the greatest $m_{k,n}$ values. This bandwidth allocation strategy maximizes the bandwidth usage efficiency but highly suffers of a inefficient energy management. In order to provide energy consumption minimization while preserving the system throughput maximization, a new parameter is introduced. It will modulate these pure opportunistic resource allocations.

B. Energy consumption minimization

The second major objective of the OEA is to provide efficient energy management in addition to the system throughput optimization. Existing opportunistic resource mapping (as MaxSNR or WFO for example) are basically horizontals. Due to flat fading during a frame, often a same user strictly experienced the greatest channel condition on each TS of a subcarrier. Consequently, with classical opportunistic schedulers, a same user often receives all the TS of a subcarrier and need to stay in active mode during a long time. Note that we can potentially have one different selected user on each available subcarrier. Consequently, during all TS, many selected users can not be set in sleep mode. They consume many power for transmitting few bit during a long time (with many allocated TS but on few subcarriers). To conclude, opportunistic scheduling is acknowledged as the best way to manage wireless resources, maximizing the system capacity and providing QoS but they need to be more energy efficient.

The OEA scheduler proposes to drastically minimize the energy consumption in particular in increasing the sleeping mode duration. This is done while trying to preserve the benefit of opportunistic strategies on system capacity. In order to achieve this goal, our proposition is to extend the classical opportunistic cross-layer design to obtain a new vertical opportunistic resource mapping (Fig. 1(b)). When a user is in active mode, OEA tries to benefit from its activation in order to compress its time of activity and to transmit more bit per “used” TS. Like this, OEA allows to significantly increase sleeping mode duration and energy preservation. OEA scheduler computes an “Energy Transmission Cost” (ETC_k) parameter (in Watt). It is based on the energy cost of user k to transmit on a RU:

$$ETC_k = A_k * Cn_k + (1 - A_k) * C1_k, \quad (6)$$

When the user k is in active mode, $A_k = 1$ else, $A_k = 0$ (i.e. sleep mode). In addition, Cn_k and $C1_k$ are two constants (in Watt). $C1_k$ represents the energy needed to wake up the user k from the sleep mode to the active mode and to transmit on its first allocated subcarrier. Cn_k represents the energy needed to transmit on a n^{th} allocated subcarrier (the user is already awake). Cn_k value is lower than $C1_k$ since the cost to transmit some supplementary bits is lower than the cost to move to sleep mode to active mode¹.

The OEA scheduling principle is then to allocate a TS of subcarrier n to the user k which provides the best “Bit Transmission Profitability” (“ $BTP_{k,n}$ ” in bit/Watt) such as:

$$BTP_{k,n} = m_{k,n} / ETC_k \quad (7)$$

This dynamic priorities allows to significantly reduce energy consumption while optimizing the global system throughput. Indeed, OEA is designed to found, in the resource allocation, the user which provides the best trade-off between these two objectives : transmitting the maximum number of bit and consuming the less energy than possible. This provides the most profitable allocation in term of bit/Watt.

Thanks to the $BTP_{k,n}$ parameters, higher priority are given to the users already awake but also to the users able to transmit the higher number of bit on the considered RU. Since $Cn_k \ll C1_k$, it is often more profitable in terms of energy consumption to continue to allocate the subcarriers to a same user rather to choose a new one for a negligible throughput gain. This allow to compress the user active mode session, maximizing the sleeping session duration and helping to reduce the energy consumption. However, if the active users experience poor radio condition, it will be more profitable to take benefit of the good potential throughput of a sleeping user which could experienced really better radio conditions due to low multipath fading. In this case, OEA scheduler set this user in active mode and allocate to him the considered RU since it can provide a better ratio of transmitted bits by Watt, i.e a better bit transmission profitability.

IV. PERFORMANCE EVALUATIONS

A. Context and simulation setup

Performance evaluation results are obtained using OPNET discrete event simulations [13]. In the simulations, we assume

¹ $C_k \gg Cn_k$, i.e. energy needed to be active \gg energy required to transmit on an additionnal RU if user already set in active mode

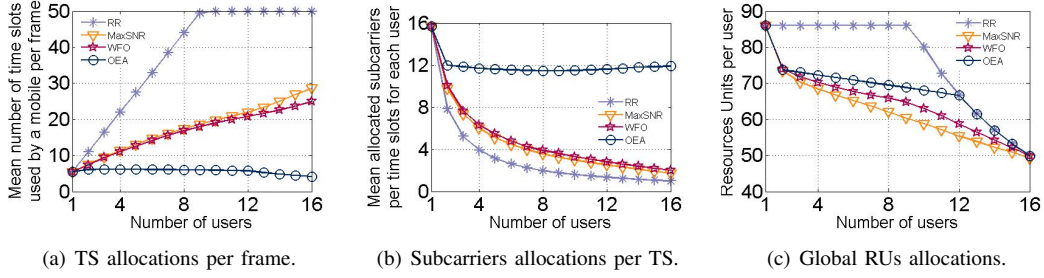


Fig. 2. Schedulers radio resources managements.

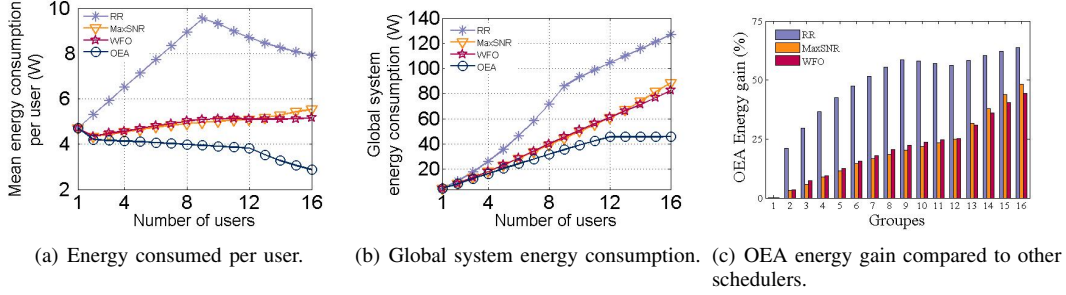


Fig. 3. Impact of scheduling strategies on network energy consumption.

a total number n_{sub} of 16 subcarriers and a total number n_{ts} of 50 TS in a frame. In addition, $C1_k$ and Cn_k are fixed respectively equal to 157 mW and 46.8 mW, for all k in accordance with measured hardware consumption. The channel gain model on each subcarrier assumes free space path loss and multipath Rayleigh fading [1]. The BER target is taken equal to 10^{-3} and the average bit rate of each Variable Bit Rate (VBR) source is assume equal to 150 Kbps.

B. Radio resources managements

Fig. 2 shows the behaviours of each scheduler in the resource allocation. Fig. 2(a) represents the average number of TS used by each user in each frame. A TS is considered as “used” by a user if the user receive at least one RU of this TS in a frame and consequently that the user can not be set in sleep mode during this one. The higher this value, the more will be users active mode duration (greedy in energy) and the more will be the energy consumption. Fig. 2(b) represents the mean number of allocated subcarrier to a same user per allocated TS (this value is range between 1 and 16). Fig. 2(c) shows the average global amount of RUs allocated to each user in a frame.

First, we can observe that with each scheduler, if we have only one user in the system, this user is not in competition with other and it receives all the subcarrier of the first TS of the frame ($n_{max} = 16$, Fig. 2(b)). In average, after the allocation of all the subcarrier of approximately 5 TS (Fig. 2(a)), the user throughput requirement is satisfied and no more allocation has been done. Note that for only 1 user in the sytem, each scheduler also provides the same allocation results since opportunistic scheduling show their benefits only if multiuser diversity exists.

Then, we can observe that, when the number of user increase, RR share the subcarrier of each TS with fairness

between all users. This is due to the nature of the RR scheduling with alternatively serve user in RUs. Having less subcarrier per TS. Each user need to use more TS which will induce more energy consumption. If we increase the number of user more than 9 (Fig. 2(a)), the system capacity is exceeded and each user used the maximum available TS in the system ($t_{max} = 50$).

Regarding MaxSNR and WFO results, we can observe that, like with RR, the subcarriers of each TS are shared between users (Fig. 2(b)). The higher the number of user, the less is the number of subcarrier allocated to a user in a TS and the more is the number of TS needed by the users. However few differences exist with RR results. First, the MaxSNR and WFO curve are above RR curve (Fig. 2(b)). In addition, the gradient of the curve is lower than the RR curve (Fig. 2(a)). Indeed, with these schedulers, the RUs are not simply shared between user but opportunistically allocated to the users with the best radio conditions during a frame and it is statistically possible to have a same user with good condition on many subcarrier in a same frame. In addition, results of Fig. 2(c) show that MaxSNR and WFO take advantage of the multiuser diversity to maximise the number of bit transmitted per RU. Higher the number of users in the system, the more efficient is the allocation process in term of system throughput since less RU are need by user.

OEA encourages vertical resource mapping. This explains why the OEA curve is below the others in fig 2(a) and above in Fig. 2(b). This shows that very few user are simultaneously in active mode. OEA wakes up only the adequate number of user in order keep good spectral efficiency. Consequently, the TS's subcarriers are shared between user but only if necessary for the transmission profitability. This will ensure a good trade-off between throughput and energy consumption.

C. Energy consumption

Fig. 3(a) and Fig. 3(b) respectively show the user and the global energy consumption. Focusing on RR curves, we can observe that, between 1 and 9 users, the mean user's energy consumption increases with the number of users. This is due to the sharing of the TS's subcarrier between users (Fig.2(b)) which induces the active mode duration increase (Fig.2(a)). With more of 9 users, the system is overloaded and RR fails to provide the sufficient amount of RUs required by each user. They are often forced to stay in sleep mode even with data to transmit due to the lack of RUs. More often in sleep mode, the user consumed less energy over the time. This explains why with more than 9 user, the RR curve decrease (Fig. 3(a)).

Like RR, MaxSNR and WFO share the TS's subcarriers between users which provides an energy consumption increase with the traffic load. However this share is less fair since it is statistically possible to have a same user with good condition on many subcarrier in a same frame. This corresponds to a more vertical allocation than RR. In addition, the usage of multi-user diversity allows to use less RUs by user when their number increase. This allows to reduce the user active mode duration and consequently the energy consumption. This explain why opportunistic scheduler curves grow more slowly than RR.

Then, let's focuses on OEA energy consumption results. We can observe that, instead to use all the multiuser diversity in order to exclusively improve system capacity, OEA uses it in order to also reduce energy consumption. Higher the number of users in the system, the more thrifty is the allocation process. In addition, when the system capacity is exceeded with OEA (more than 12 users), it is interesting to note that the global energy consumption is stabilized to a low level. Contrary to other schedulers which wake up many users in order to transmit few bits simultanously on many TS's subcarriers, OEA prefers to maximize the RUs utility (i.e. the number of bits transmitted per Watt consumed). Whatever the traffic load considered, few, but always the sufficient number of users, are simultaneously activate in order to provide good, but not energy expensive, spectral efficiency. Increasing the sleep mode duration, OEA provides an important energy gain if compared to other schedulers.

D. Spectral efficiency

Highly relies on Fig. 2(c), the Fig. 4 shows the spectral efficiency of each allocation and their abilities to optimized or not the system capacity. MaxSNR and WFO are acknowledged as the best schedulers regarding this network performance criterion. The OEA, which besides minimizes energy consumption, can not ensure the same level of throughput optimization but it is interesting to note that this strategy stay opportunistic and throughput efficient. Indeed, OEA scheduler takes benefit of radio conditions and multi-user diversity. This provides a throughput gain which is nevertheless significant compared to RR scheduler.

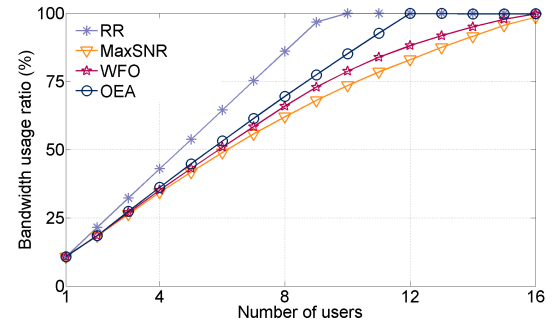


Fig. 4. System capacity study.

V. CONCLUSION

The OEA scheduler is a part of sustainable development approach. Maximizing the number of bits transmitted per Watt consumed, the OEA scheduler allows to reduce energy consumption of wireless communication networks without compromising too much their effectiveness characterized has high spectral efficiency. This proposed research can have several impacts: environmental and economicals. First, OEA allows significant reduction of the energy footprint of wireless computer equipment. Consequently, it helps to decrease the alarming world greenhouse gas emissions. Then, OEA increases the lifetime of our equipment on battery. This allows reducing electrical load time and lowering operating costs. Future works will focus on OEA improvements. We will try to minor the existing trade-off between throughput maximization and energy consumption decrease.

REFERENCES

- [1] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.
- [2] J. Nagle, "On packet switches with infinite storage," *IEEE Transactions on Communications*, vol. 35, no. 4, pp. 435 – 438, April 1987.
- [3] C. Y. Wong and R. S. Cheng, "Multiuser OFDM with adaptive subcarrier, bit, and power allocation," *IEEE J. Sel. Areas Commun.*, 1999.
- [4] X. Wang and W. Xiang, "An OFDM-TDMA/SA MAC protocol with QoS constraints for broadband wireless LANs," *ACM/Springer Wireless Networks*, vol. 12, no. 2, pp. 159 – 170, 2006.
- [5] C. Gueguen and S. Baey, "Scheduling in OFDM wireless networks without tradeoff between fairness and throughput," in *Proc. IEEE Int. Vehicular Technology Conference (VTC)*, Sept. 2008.
- [6] C. Gueguen and S. Baey, "A fair opportunistic access scheme for multiuser OFDM wireless networks," *Journal on Wireless Communications and Networking. European Association for Signal Processing (EURASIP). Special issue: Fairness in Radio Resource Management for Wireless Network*, Feb. 2009.
- [7] V. de Beek et al., "A time and frequency synchronization scheme for multiuser OFDM," *IEEE J. Sel. Areas Commun.*, vol. 17, Nov. 1999.
- [8] S. K. Jayaweera, "Energy analysis of mimo techniques in wireless sensor networks," *38th Annual Conference on Information Sciences and Systems CISS 04*, 2004.
- [9] M. Andrews, K. Kumaran, and K. Ramanan, "Providing quality of service over a shared wireless link," *IEEE Communications Magazine*, vol. 39, pp. 150–154, Feb. 2001.
- [10] Y. G. Li, N. Seshadri, and S. Ariyavisitakul, "Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels," *IEEE J. Sel. Areas Commun.*, vol. 17, no. 3, pp. 461 – 471, 1999.
- [11] T. E. Trueman and R. W. Brodersen, "A measurement-based characterization of the time variation of an indoor wireless channel," in *Proc. IEEE Int. Universal Personal Communications Record (ICUPC)*, 1997.
- [12] J. G. Proakis, *Digital Communications*. New York: McGraw-Hill, 1995.
- [13] OPNET simulator, "http://www.opnet.com/,"